S. Stone
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BTeV Physics, The Staged Detector & Some Physics Reach Comparisons with LHCb

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The Physics: General

Mysteries

Solutions:
New Physics

Dark Matter

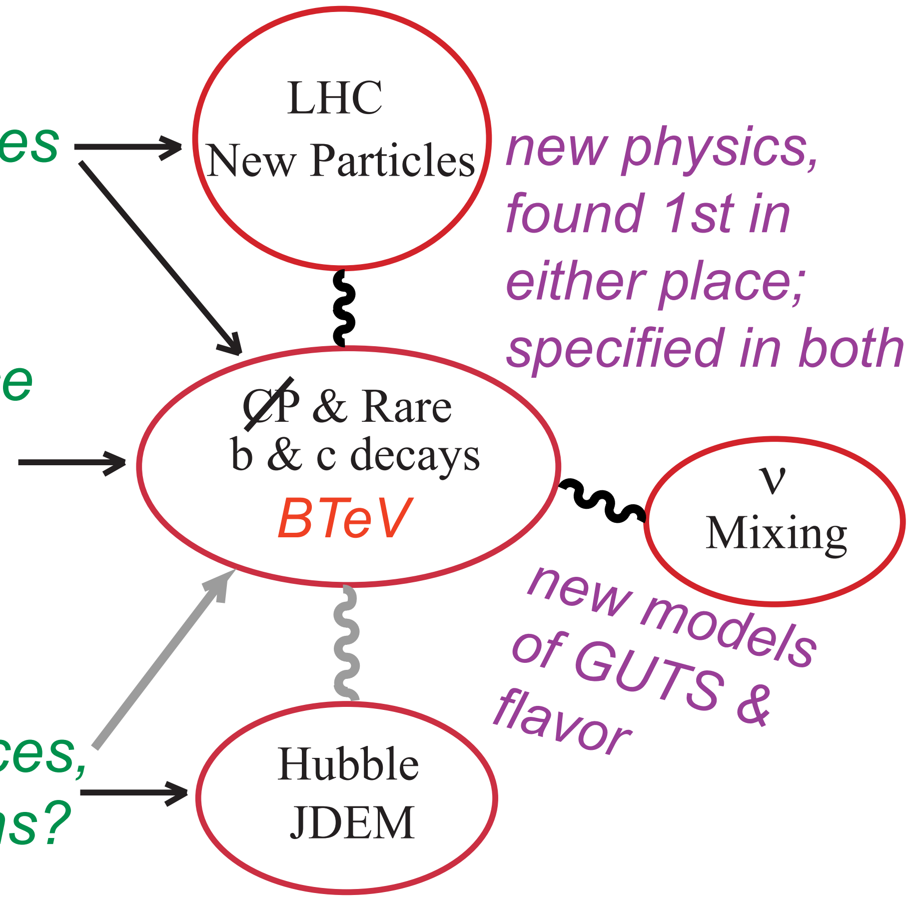
new particles

Dominance of Matter over Antimatter

new source of CP violation

Dark Energy

? new forces, dimensions?



The Physics

- There is New Physics out there: Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
- BTeV will Investigate:
  - Major Branches
    - *New Physics* via ~~CP~~ phases
    - *New Physics* via Rare Decays
    - Precision determination of CKM Elements (small model dependence)
  - Other Branches (some)
    - Weak decay processes, $\cancel{B}$'s, polarization, Dalitz plots, QCD…
    - Semileptonic decays including Λ_b
    - b & c quark Production
    - Structure: B baryon states
    - B_c decays

>>100 thesis topics

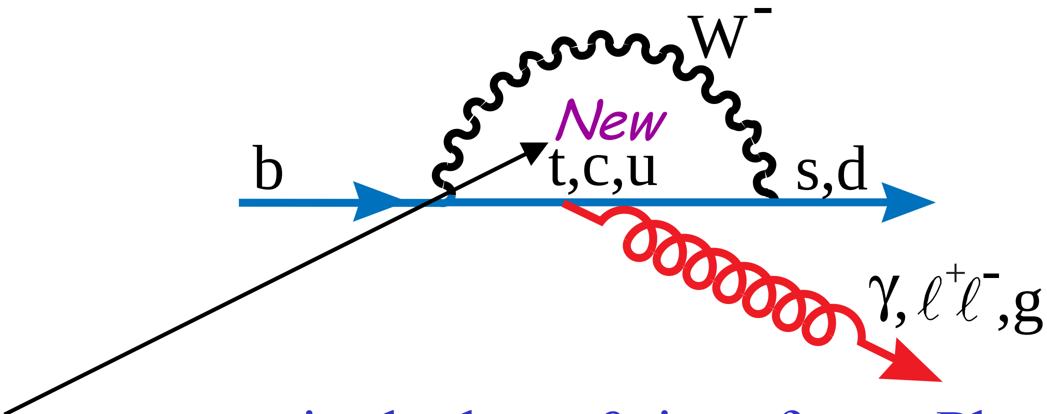
BTeV/C0

Physics Goals

- Discover or set stringent limits on "New Physics," from b & c decays
- "New Physics" is needed for several reasons
  - Hierarchy Problem – *SM can't explain smallness of weak scale compared to GUT or Planck scales*
  - Plethora of "fundamental parameters," *i.e. quark masses, mixing angles, etc…*
  - SM CP parameter not large enough to explain baryon asymmetry of the Universe-*could see new effects in b and/or c decays*

The Physics: More Specific

- CP Violation: Particles behave differently than antiparticles
  - Demonstrated in B decays by BaBar & Belle (one ∠ measured, β)
  - But there are 4 different angles to determine: α, β, γ, χ
  - Different incarnations of New Physics affect these angles in different ways. New Physics can show up as inconsistencies between/among CP measurements and other quantities.
- Rare Decays



  - New Particles can appear in the loop & interfere – Phases of the new physics can be investigated

Current Hints of New Physics

- These ratios "should be" 1:

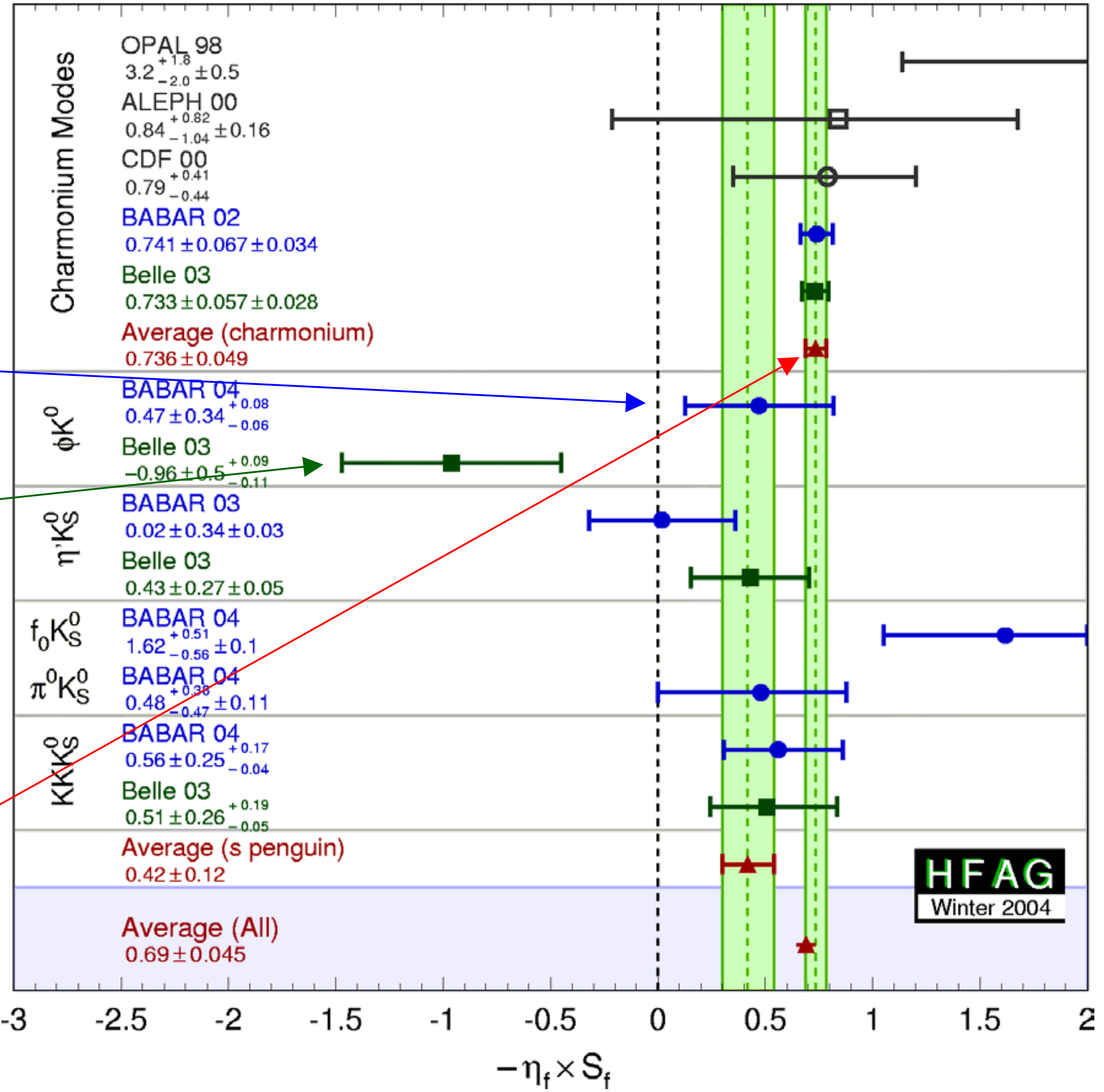
$$2\left[\frac{\mathrm{B}(B^{+}\rightarrow\pi^{o}K^{+})}{\mathrm{B}(B^{+}\rightarrow\pi^{+}K^{o})}\right]=1.17\pm0.12,\quad \frac{1}{2}\left[\frac{\mathrm{B}(B^{o}\rightarrow\pi^{+}K^{-})}{\mathrm{B}(B^{o}\rightarrow\pi^{o}K^{o})}\right]=0.76\pm0.10$$

- May be caused by NP mimicking electroweak penguins (see Buras et al hep-ph/0312259, Nandi & Kundu hep-ph/0407061)
- Nandi & Kundu say look at $B\rightarrow\rho\gamma$ CPV as $b\rightarrow d$ penguin amplitude should have a NP component
- Buras says $\Rightarrow$ "spectacular effects in forward-backward asymmetry in $B\rightarrow K^{*}\mu^{+}\mu^{-}$" due to NP, also effects in $b\rightarrow s$ penguin such as $B\rightarrow\phi K_{s}$

New Physics in b→s penguins?

- Example $B^o \to \phi K_s$ CP Asymmetry should = sin2β ? Babar: 0.47±0.34±0.07, Belle: -0.96±0.50±0.10

in $J/\psi\ K_s$ sin2β = 0.74±0.05.



Specific New Physics Models

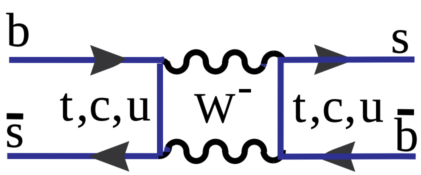
- I will discuss next the predictions of a very few of the many New Physics Models

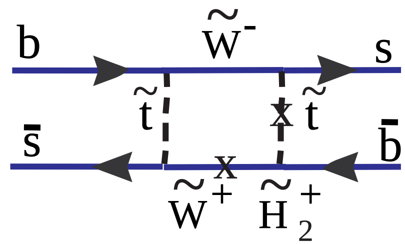
MSSM Measurements from Hinchcliff & Kersting

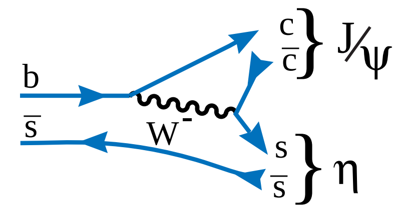
(hep-ph/0003090)

- Contributions to B_s mixing

$B_s \to J/\psi\eta$



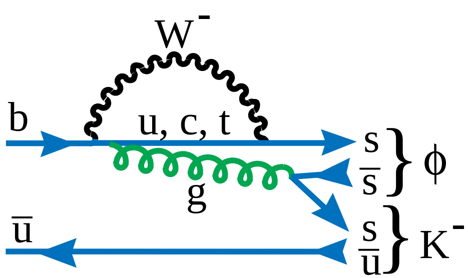


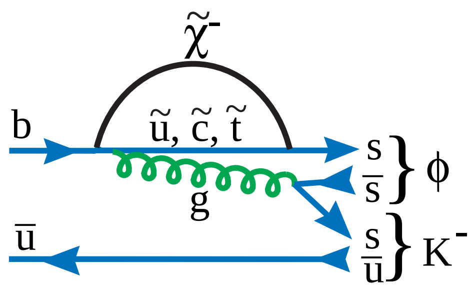


CP asymmetry $\approx 0.1\sin\phi_\mu\cos\phi_A\sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

$B^- \to \phi K^-$





Asym$=(M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM

Specific New Physics Case: SUSY

- Scenario: LHC finds new states say squarks
- These states have a mass matrix; the diagonal terms are found at LHC; the off-diagonal terms effect flavor physics & are measurable by BTeV as they are new sources of CP phases, etc.

$$(m_{\tilde{q}}^2)_{ij} = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

- Okada considers 3 models ("SUSY in B decays," SuperB workshop, Hawaii, 2004)
  - Minimal supergravity model (S.Belrolini, F.Borzumati, A.Masiero, and G.Ridorfi, 1991)
  - SU(5) SUSY GUT with right-handed neutrino (S.Baek,T.Goto,Y.O, K.Okumura, 2000,2001;T.Moroi,2000; N.Aakama, Y.Kiyo, S.Komine, and T.Moroi, 2001, D.Chang, A.Masiero, H.Murayama,2002; J.Hisano and Y.Shimizu, 2003)
  - MSSM with U(2) flavor symmetry (A.Pomarol and D.Tommasini, 1996; R.Barbieri,G.Dvali, and L.Hall, 1996; R.Barbieri and L.Hall; R.Barbieri, L.Hall, S.Raby, and A.Romonino; R.Barbieri,L.Hall, and A.Romanino 1997; A.Masiero,M.Piai, and A.Romanino, and L.Silvestrini,2001; ….)

Pattern of Deviation from SM

√√ large deviation √ sizable deviation — small deviation

	B_d-unitarity	ε	$\Delta m(B_s)$	$B_d \to \phi K_s$ CP	$B \to M_s\gamma$ indirect CP	$b \to s\gamma$ direct CP
mSUGRA	closed	—	—	—	—	√
SU(5)SUSY GUT + ν_R (degenerate)	closed	√√	—	—	√	—
SU(5)SUSY GUT + ν_R (non-degenerate)	closed	—	√√	√√	√√	√
U(2) Flavor symmetry	√√	√√	√√	√√	√√	√√

T.Goto,Y.Okada,Y.Shimizu, T.Shindo, and M.Tanaka

Specific New Physics Case: Warped ED

- One warped Extra Dimension (Agashe, Perez & Soni hep-ph/0406101). Uses Randall-Sundrum scenario (RS1)
- Effects extractions of α, β, γ, χ, & Δm_s
- Effects rates & asymmetries in $B\rightarrow s\ell^+\ell^-$

	B_s mixing	$CP(B_s \rightarrow J/\psi\ \eta)$	$CP(B_d \rightarrow \phi\ K_s)$	$\mathcal{B}(b\rightarrow s\ell^+\ell^-)$
RS1	$\Delta m_s^{SM}\,[1+O(1)]$	$O(1)$	$\sin 2\beta \pm O(0.2)$	$\mathcal{B}^{SM}[1+O(1)]$
SM	Δm_s^{SM}	λ^2	$\sin 2\beta$	$\mathcal{B}^{SM}$
	$CP(B_d \rightarrow K^*\gamma)$	$CP(B_s \rightarrow \phi\ \gamma)$	$CP(B_d \rightarrow \rho\ \gamma)$	$CP(B_s \rightarrow K^*\gamma)$
RS1	$O(1)$	$O(1)$	$O(1)$	$O(1)$
SM	$\frac{m_s}{m_b}\sin 2\beta$	$\frac{m_s}{m_b}\lambda^2$	$\frac{m_d}{m_b}\lambda^2$	$\frac{m_s}{m_b}\sin 2\beta$

$\lambda^2 \approx 0.05$

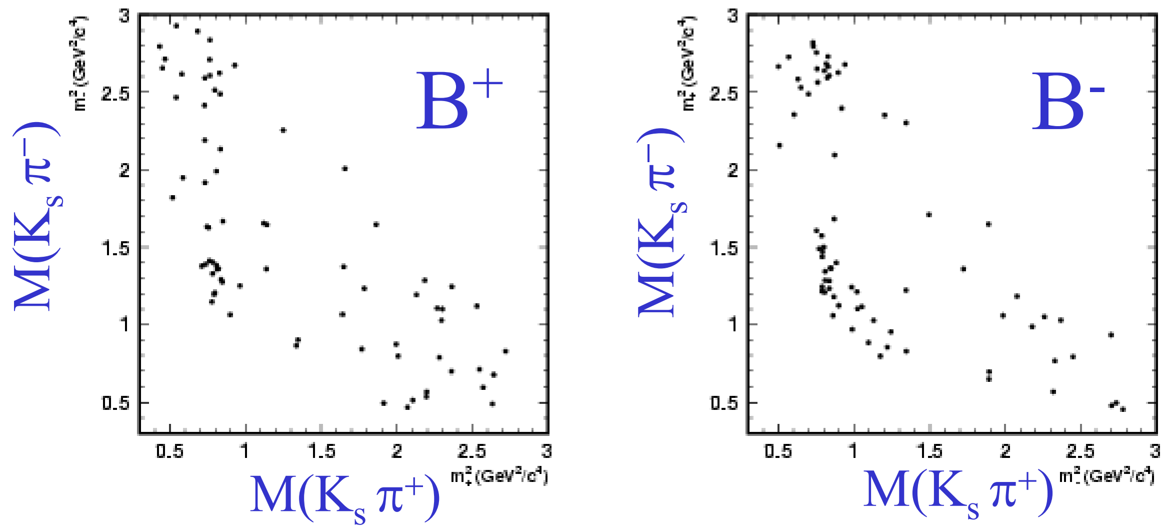
Some of BTeV's Physics Reach in 2 fb^{-1} (CKM)

Reaction	$\mathcal{B}$(B)(x10^{-6})	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8°
$B^o \to J/\psi K_S$ $J/\psi \to l^+ l^-$	445	168,000	10	sin(2β)	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13°
$B^- \to K_S \pi^-$	12.1	4,600	1		<4° +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4°
$B_s \to J/\psi\ \eta$,	330	2,800	15		
$B_s \to J/\psi\ \eta'$	670	9,800	30	sin(2χ)	0.024

Just because a mode isn't listed, doesn't mean we can't do it!

Measurement of γ using $B^{\pm}\rightarrow D^oK^{\pm}$, $D^o\rightarrow K_s\pi^+\pi^-$

- Belle recently used this mode (& the D^{*o} mode) to make a first stab at measuring γ using the Dalitz plot difference between B^+ and B^-



- $\gamma = 77^o\pm18^o\pm13^o\pm11^o$ (there is two-fold ambiguity: $\gamma+\pi$, $\delta+\pi$)
- Belle: 140 fb^{-1}, DK 146 events, D*K 39 events
- BTeV in 1.6 fb^{-1} 3024 DK events!

Some of BTeV's Physics Reach in 2 fb^{-1}(NP)

Comparison with e^+e^- B factories

Mode	BTeV (2 fb^{-1})			B-fact (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi\eta^{(\prime)}$	12650	1645	>15	-	-	
$B^- \to \phi K^-$	11000	11000	>10	700	700	4
$B^o \to \phi K_s$	2000	200	5.2	250	75	4
$B^o \to K^*\mu^+\mu^-$	2530	2530	11	~50	~50	3
$B_s \to \mu^+\mu^-$	6	0.7	>15	0		
$B^o \to \mu^+\mu^-$	1	0.1	>10	0		
$D^{*+} \to \pi^+ D^o$, $D^o \to K\pi^+$	~10^8	~10^8	large	$8x10^5$	$8x10^5$	large

Opportunities using $\Delta\Gamma$ of B_s

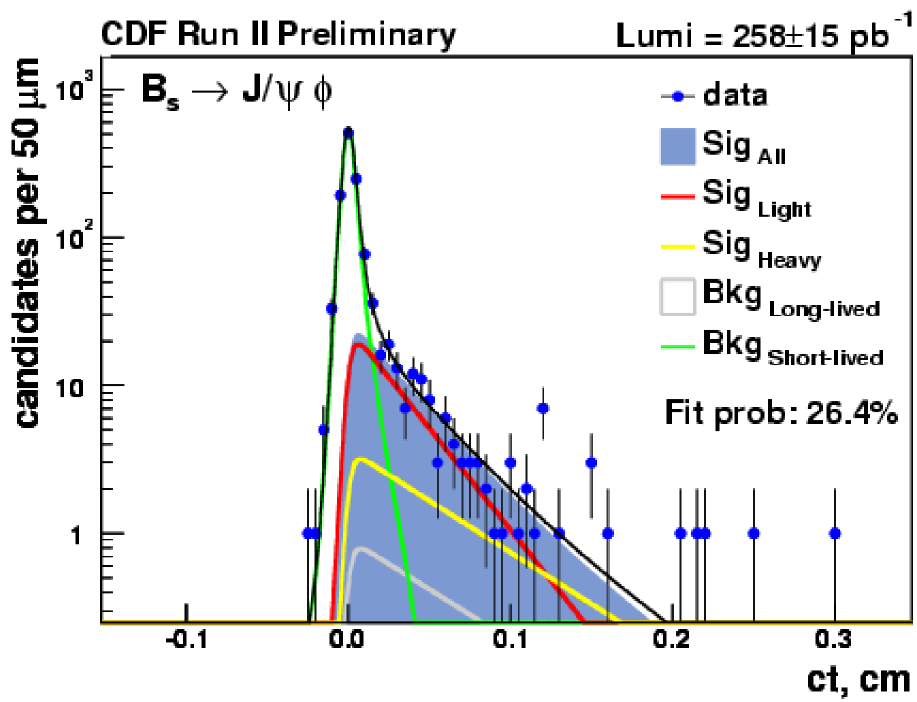
- CDF reports

$$\frac{\Delta\Gamma}{\Gamma} = 0.65^{+0.25}_{-0.33} \pm 0.01$$

- Much larger than SM expectations of 12±6 %

(U. Nierste hep-ph/0105215)

- If $\Delta\Gamma/\Gamma$ >~10%, then there are more opportunit with B_s mesons



  - ➢ For example the discreet ambiguities in γ using $B_s \to D_s K^-$ are resolved
  - ➢ Untagged decay distributions in $B_s \to J/\psi\ \eta^{(\prime)}$, $B_s \to J/\psi\ \phi$ can be used to measure χ

Super-BaBar

- Idea is to go to $\mathcal{L}=10^{36}$. This would compete with BTeV in B^o & B^- physics, but not in B_s etc.
- **Problem areas**
  - **Machine:** Stu Henderson in his M2 review at Snowmass said: *“Every parameter is pushed to the limit-many accelerator physics & technology issues”*
  - **Detector:** Essentially all the BaBar subsystems would need to be replaced to withstand the particle densities & radiation load. (See E2 report **hep-ex/0201047)**
  - Physics estimates are based on achieving same performance with brand new undeveloped technologies

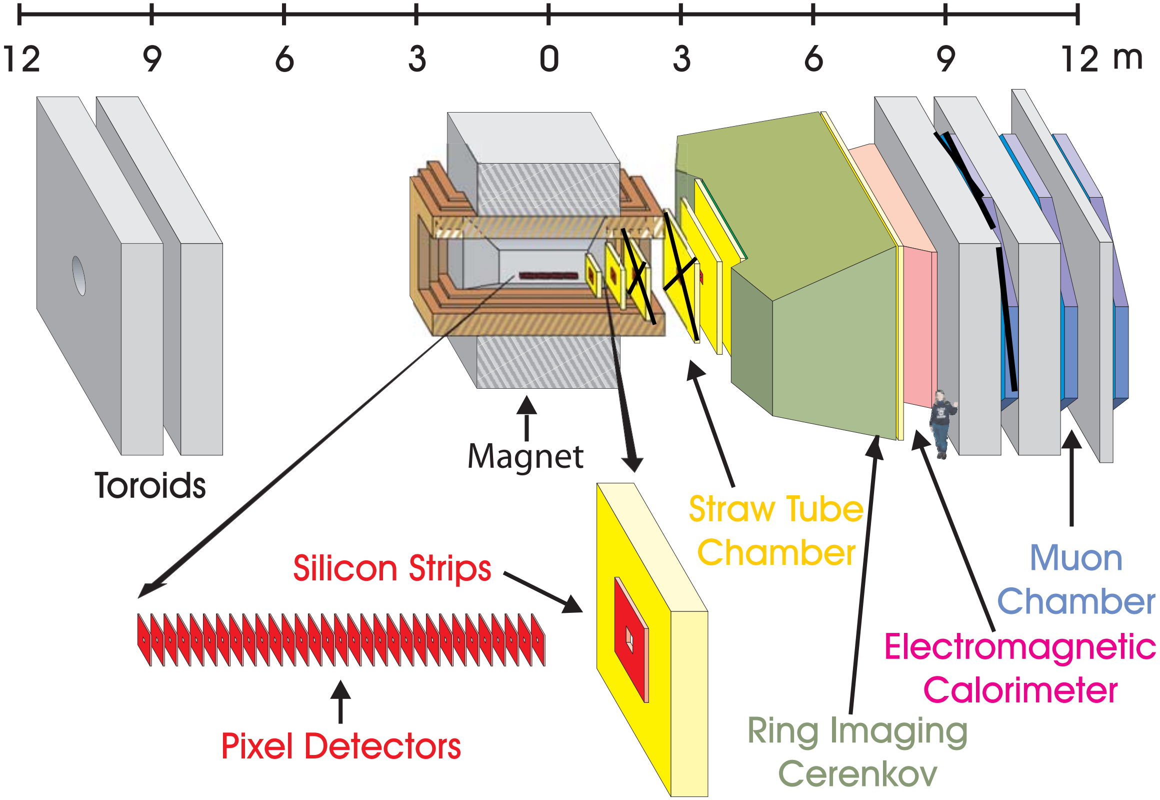
Super-BaBar

- Examples of Detector problems *(from the E2 summary)*
  - "To maintain the vertex resolution & withstand the radiation environment, pixels with a material budget of 0.3% X_o per layer are proposed. Traditional pixel detectors which consist of a silicon pixel array bump-bonded to a readout chip are at least 1.0% X_o. To obtain less material, monolithic pixel detectors are suggested. This technology has never been used in a particle physics experiment."
  - "As a drift chamber cannot cope with the large rates & large accumulated charge, a silicon tracker has been proposed. At these low energies track resolution is dominated by multiple scattering. Silicon technology is well tested but is usually used at this energy for vertexing, not tracking. Realistic simulations need to be performed to establish if momentum resolution as good as BABAR can be achieved with the large amount of material present in a silicon tracker."
  - "There is no established crystal technology to replace the CsI(Tl)."
  - "There is no known technology for the light sensor for the SuperDIRC."

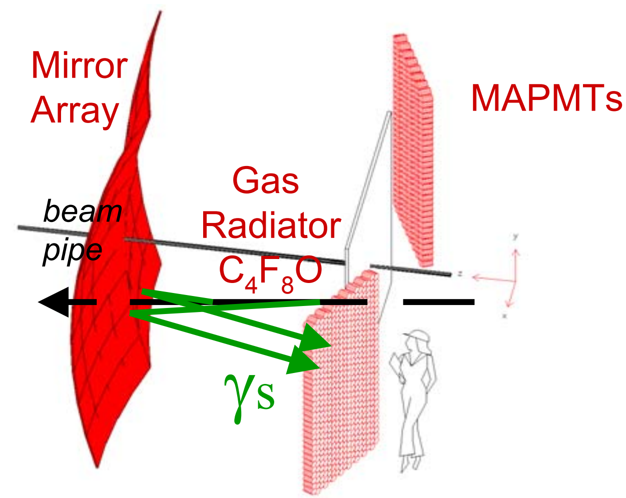
Our View on Super-BaBar

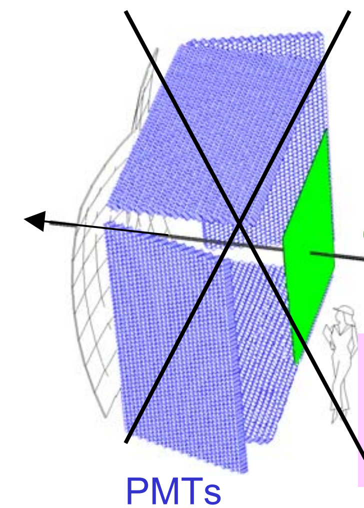
- It would take a 10^{36} e^+e^- collider operating on the Y(4S) to match the performance of BTeV on B^o & $B^{\pm}$ mesons, while there would be no competition on B_s, Λ_b, etc..
- There are serious technical problems for both the machine & the detector
- We believe the cost will far exceed that of BTeV, and there is no official cost estimate.

BTeV's Staged Detector



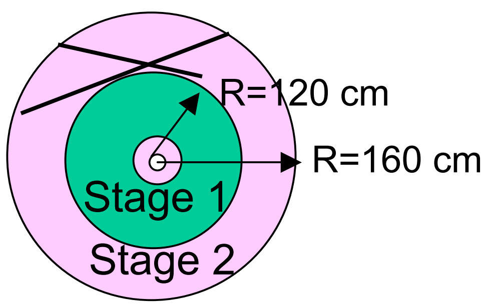
Two-component RICH





Only Top PMTs in Stage I

Electromagetic Calorimeter



BTeV's Staged Detector - Details

- Stage I detector
  - 50% of EM cal - *we retain 60% of the rate on neutrals*
  - No liquid radiator system - *we retain 75% of flavor tagging rate*
  - Straw stations 3 & 4 are missing, as are Silicon stations 3, 4 & 7 - *no real physics effects, these are for redundancy*
  - No dimuon trigger & only 2 muon tracking stations - *no real effects, the dimuon trigger is a useful systematic check but can come later*
  - 50% of the trigger & DAQ highways - *no real effects on b's as there is alot of "head room" in the system and we can give up some charm initially*
- Stage II detector adds in all the missing components

BTeV's Schedule

- Stage I starts August 1, 2009
- Then we run until July 1, 2010
  - Expect about 1 month to commission IR
  - Expect about 1 month commissioning time then we produce physics (See Joel's talk)
- Summary of Stage 1
  - Estimate 6 months running time
  - Lab says that we will run 10 months a year and get 1.6 fb^{-1}
  - Thus this is a 1 fb^{-1} run
  - We have 75% of our "normal" rate on all charged flavor tagged modes
  - We have 75% x 60% = 45% of our "normal" rate on flavor tagged modes with neutrals
- Some Commissioning done before on wire target or at end of stores and during the 1 month IR commissioning – *New IR has 2.5 x $\mathcal{L}$ than when BTeV was approved by P5!*

LHC & LHCb's Schedule

- LHC running in steady state
  - In steady state mode, after a few years, they are scheduled to run 160 days a year for physics MINUS running for Heavy Ions - estimate 139 days on pp (see Collier, Proc. Chamonix XII, March 2003, CERN-AB-2003-008 ADM)
  - LHCb will start running at $2.8\text{x}10^{32}$; this gives using the formula in Collier 0.8 fb^{-1} per calendar year
- LHCb initial running constraints
  - Initially plan to set β^* 100 x ATLAS/CMS, to avoid multiple interactions/crossing as 1st runs will be with 1632 ns bunch spacing to avoid necessity of crossing angle (Here LHCb needs special set up to see collisions since they are displaced by 11.2 m from interaction region center)
  - First year will see limited running at 75 ns bunch spacing; LHCb will run at $2/3\ \text{x}10^{32}$ to avoid multiple int/xing. Second year will switch from 75 ns to 25 ns "when possible"

LHCb's Schedule

- LHC schedule (LHCb-1)
  - Nominal: start April 1, 2007
  - We predict LHCb 2007 integrated luminosity to be 0.1 fb^{-1}
  - Since the 1st quarter of 2008 is still in the 1st year of tuning they will collect 0.6 fb^{-1}
  - They get the full 0.8 fb^{-1} in 2009
- But - this schedule has no contingency

LHCb's Schedule 2

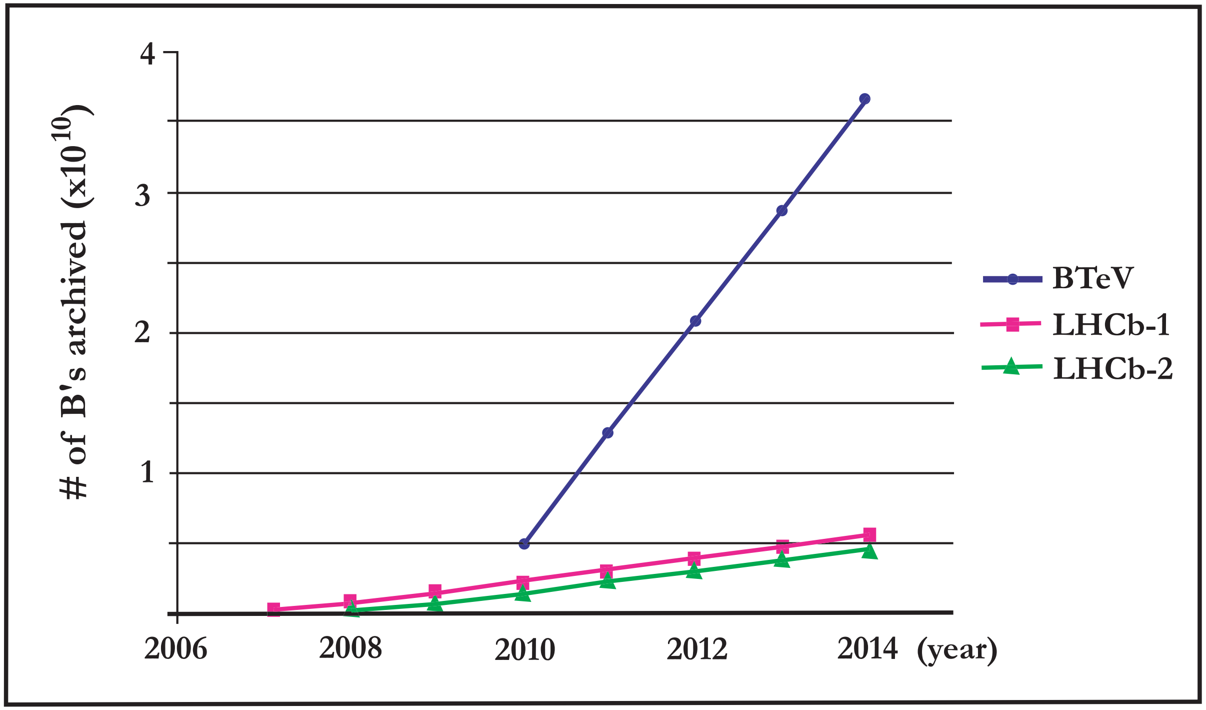
- Therefore we choose to set up an alternate schedule similar to the one that we have that has lots of float. A defensible schedule has ~ 12 months of float implying:
  - 0 fb^{-1} in 2007
  - 0.1 fb^{-1} in 2008
  - 0.6 fb^{-1} in 2009
  - 0.8 fb^{-1} in 2010 and beyond
- Neither for BTeV or LHCb is detector commissioning considered in what follows: we assume it will factor out of the comparisons
  - BTeV has some commissioning on wire target etc…
  - LHCb has limited accesses due to interference with ATLAS, CMS, etc..

Yearly Integrated Luminosity Assumptions

fb^{-1}

	2007	2008	2009	2010	2011	2012	2013	2014	Sum
LHCb-1	0.1	0.6	0.8	0.8	0.8	0.8	0.8	0.8	5.5
LHCb-2		0.1	0.6	0.8	0.8	0.8	0.8	0.8	4.7
BTeV				1.5	1.6	1.6	1.6	1.6	7.9

Comparison I - Total number of B's to "tape"

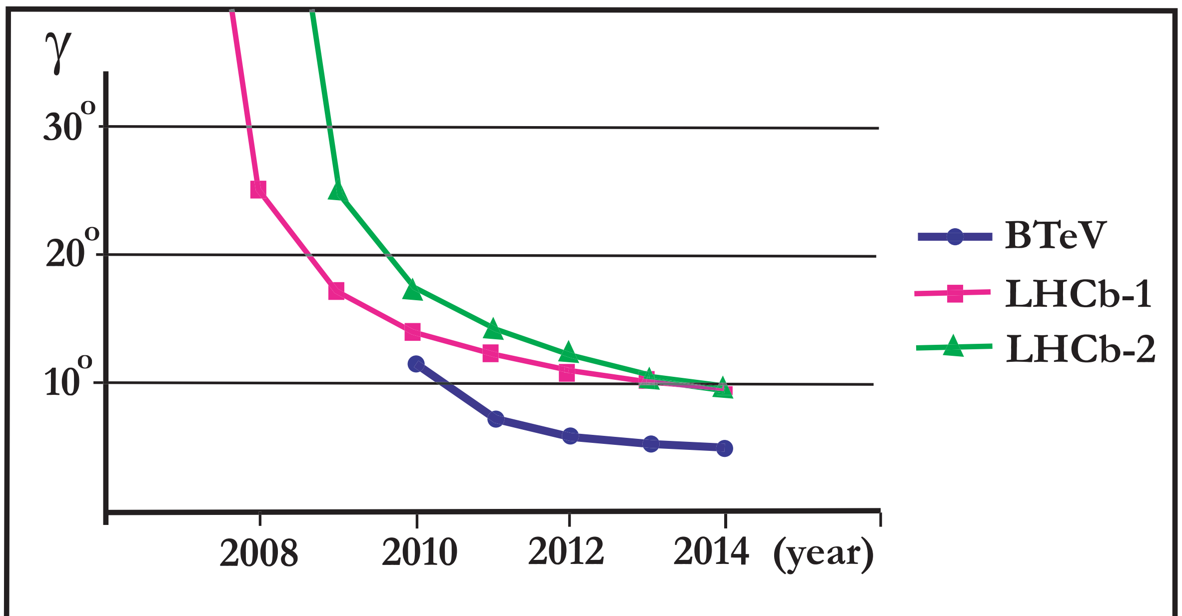


- For BTeV we take 1/2 the nominal rate in 2010 due to the staged detector
- BTeV is better by 5x from Trigger-DAQ & 2x from running time, giving a factor of 10 $b\bar{b}$'s to tape
- e^+e^- at 1000 fb^{-1} would have 0.1 $\times 10^{10}$ $b\bar{b}$'s

Measuring γ Using $B_s \rightarrow D_s K^-$

	BTeV Stage I	BTeV Stage II	LHCb[11]
Yield (2 fb^{-1})	6,750	6,750	7,140
S/B	7	7	>1
$\epsilon \cdot D^2$	9.8%	13%	7.1%
Tagged yield (2 fb^{-1})	660	878	507
Error in γ for 2 fb^{-1}	9.4°	8.4°	14.5°
Error in γ/year (steady state)		10.9°	22.9°

From LHCb Light TDR



Conclusion on Measuring γ in $B_s \to D_s K^-$

- What is a meaningful measurement of a CP violating angle?
  - Example $B^o \to \phi K_s$ CP Asymmetry = $\sin 2\beta$ Babar: $0.47 \pm 0.34 \pm 0.07$, Belle: $-0.96 \pm 0.50 \pm 0.10$

    in $J/\psi\ K_s$ $\sin 2\beta = 0.74 \pm 0.05$. Thus both measurements are not definitive and both have an error in $\beta \sim 14^o$. Need $\delta\beta < 10^o$ or better!
- *Thus LHCb will not likely have a meaningful measurement of γ in either of their turn on scenarios before BTeV, nor will they ever make a measurement as good as BTeV's*

Measuring α using $B^o \rightarrow \rho\pi$

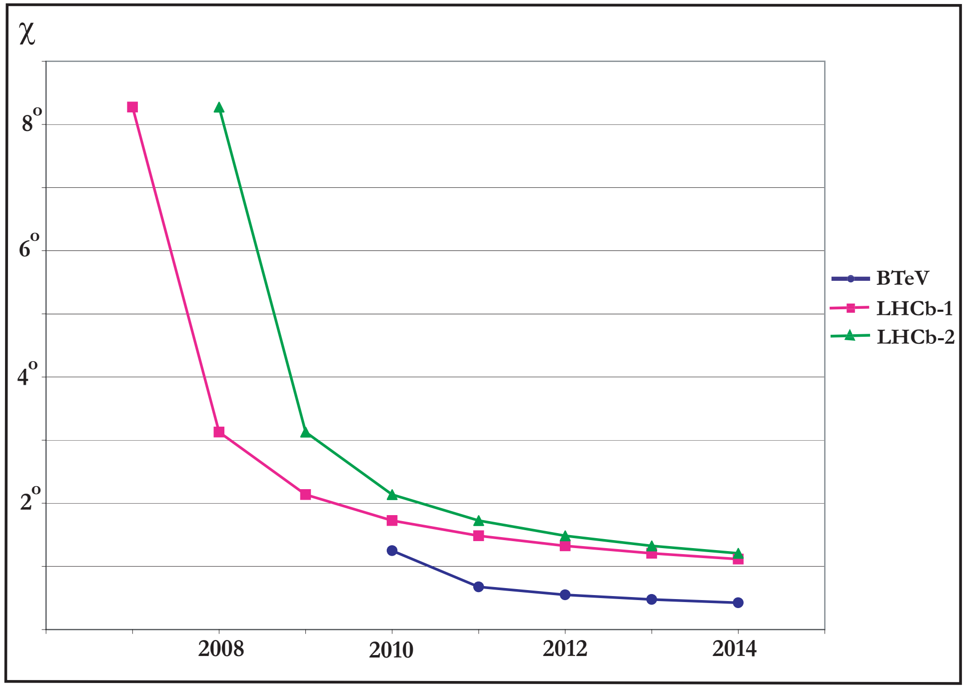
- LHCb
  - Shaslik-style Pb-scintillating fiber device, energy resolution $10\%/\sqrt{E} \oplus 1.5\%$ BTeV's is $1.7\%/\sqrt{E} \oplus 0.55\%$
  - The LHCb detector segmentation is 4x4 cm^2 up to 90 mr, 8x8 cm^2 to 160 mr and 16x16 cm^2 at larger angles. (The distance to the interaction point is 12.4 m.) Thus the segmentation is comparable to BTeV only in the inner region. (BTeV has 2.8 x 2.8 cm^2 crystals 7.4 m from the center of the interaction region.)
  - In 2 fb^{-1} 7260 events, S/B <1/7.1, no estimate from LHCb of $\delta\alpha$, we find 11.7^o from these #'s compared to BTeV Stage I 6.3^o
- *Since LHCb will accumulate only half the integrated luminosity of BTeV per year, it is clear that they will not be able to make a definitive measurement of α, in fact, it is likely that they will not be able to make one at all, not surprising because of the poor energy resolution and segmentation of their calorimeter.*

Measuring χ in B_s decays

- Modes
  - BTeV uses CP eigenstates: $J/\psi\ \eta^{(\prime)}$
  - LHCb uses $J/\psi\ \phi$, VV mode so they must do a transversity analysis
- CDF & D0 get 1 $J/\psi\ \phi$ each per pb^{-1} $\Rightarrow \delta\chi \sim 13^o$ in Run II, **if** B_s mixing is also measured (sets a floor on $\int L$)

	BTeV Stage I	BTeV Stage II	LHCb[11]
Yield (2 fb^{-1})	6,800	11,340	100,000
S/B	20	20	>3
$\epsilon \cdot D^2$	9.8%	13%	5.5%
Tagged yield (2 fb^{-1})	660	1474	5500
Error in χ for 2 fb^{-1}	1.1°	0.7°	1.9°
Error in χ/year (steady state)		0.9°	3.0°

Conclusions on χ



This compares
BTeV ($B_s \to J/\psi\ \eta^{(\prime)}$)
with
LHCb ($B_s \to J/\psi\ \phi$)
BTeV can also use the $J/\psi\ \phi$ mode

LHCb will have a chance in 2009 of making a significant measurement of χ, if it is in excess of ~10° and they collect sufficient integrated luminosity to improve over the combined CDF & DO measurement. At the end of 2010 BTeV will have the best measurement of χ and the error will eventually be less than 0.5°.

Thus BTeV has the best chance of making a significant measurement if new physics is present and is the only detector that can measure χ if new physics doesn't make a very large contribution.

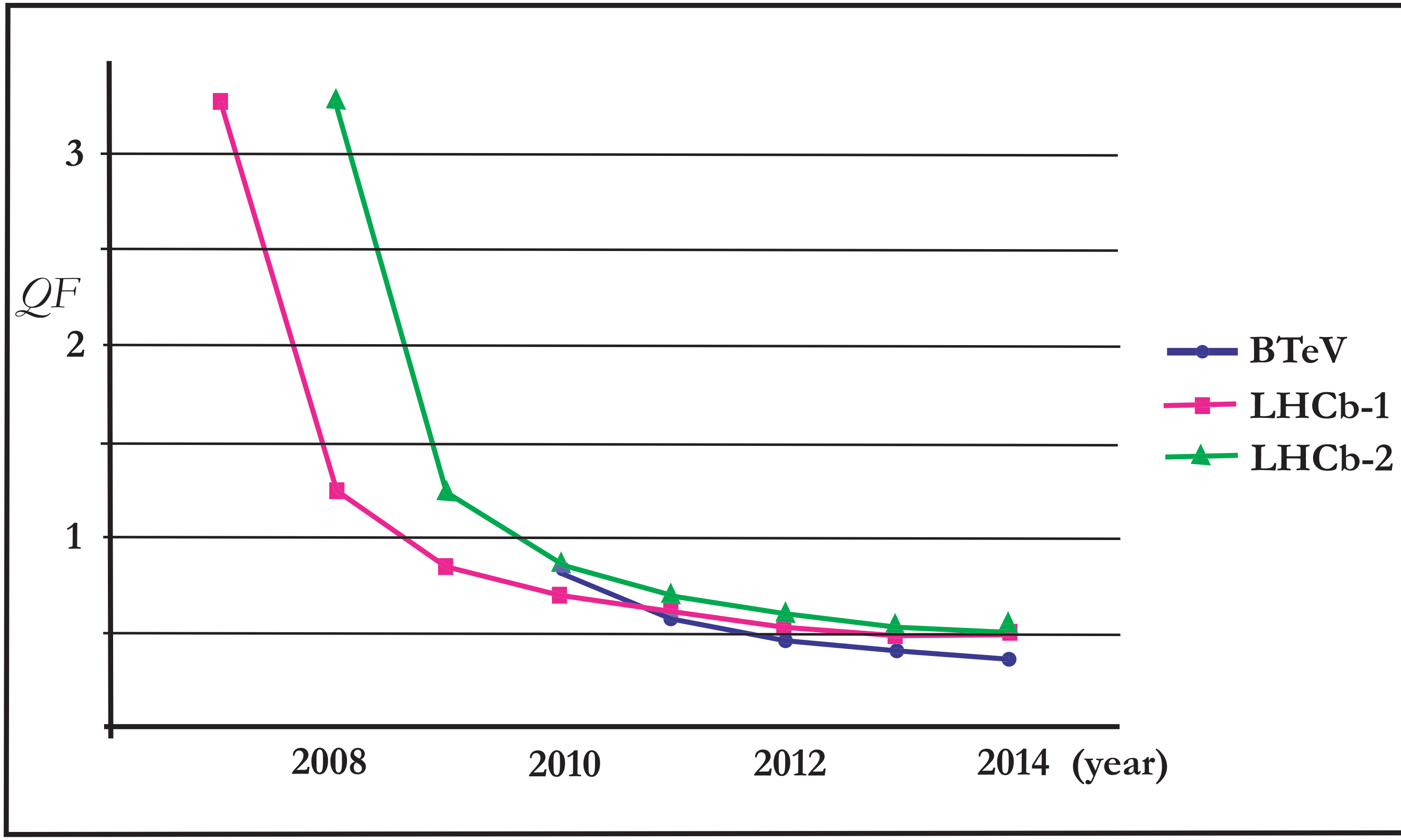
The Rare Decay $B^o \to K^{*o}\mu^+\mu^-$

- Want to measure the polarization
- No flavor tagging here
- Define $QF = \sqrt{1000/(\#\, of\ events)} \times \sqrt{(S+B)/S}$

	BTeV	LHCb[11]
Yield (2 fb^{-1})	2277	5546
S/B	7	>0.5
QF	0.71	0.74
Yield in 1 calendar year	1700	2218
QF/year steady state	0.8	1.2

- BTeV eventually overtakes LHCb

Time dependence of $B^o \rightarrow K^{*o}\mu^+\mu^-$



- This is LHCb's best case: They trigger on dimuons, there is no flavor tagging, and yet BTeV eventually has smaller errors

Conclusions on Staged BTeV vs LHCb

- The LHC turn on will be a long process by their own projections. Latest information (CMS May review), it will not start before August 2007
- LHCb will have trouble dealing with initial 75 ns running
- There may be some relatively high rate physics that can be done with with the luminosity accumulated by LHCb before BTeV catches up like B_s mixing, if CDF & D0 don't do it first, but for most of the physics, BTeV will be taking data before LHCb overtakes what the B factories and Tevatron exp. have already done. After 2010 BTeV's physics reach will dominate in all areas

General Conclusions

- BTeV due its unique elements is able to make the most comprehensive investigations of effects of New Physics in the Heavy Flavor sector
- These unique elements include: the pixel detector, the detached vertex trigger and the $PbWO_4$ crystal calorimeter
- My experience has been that having an excellent detector and a dedicated group of experimenters produces physics well beyond that conceived at the proposal stage
- The BTeV family is now poised to build the worlds best b physics experiment on time and within budget